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The environmental sustainability implications of contrast media supply chain disruptions during the COVID-19 pandemic: A document analysis of international practice guidelines

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ABSTRACT

Introduction: Travel restrictions implemented during the acute phases of the COVID-19 pandemic disrupted supply chain for critical radiology consumables including contrast media (CM) leading to shortages. Consequently, some departments had to restructure their clinical workflows in accordance to recommended guidelines to ensure safe continuity of patient care. This study aimed to summarise the temporary crisis-driven recommendations with implicit environmental sustainability essence and to analyse how these measures might inform the development of a more sustainable, long-term clinical guideline for safer and cost-effective CM usage without compromising diagnostic quality.

Methods: Documents were obtained through an electronic database search together with a relevant manual search in Google Scholar and relevant reference lists. The selected documents were subjected to a pre-defined eligibility criteria for inclusion. The READ approach was employed for document analysis and a thematic analysis of the obtained data was conducted.

Results: Of the 17 documents included, 70% (n = 12) emanate from the United States of America. The summary of the findings relate to minimising CM usage through strategic clinical approaches including optimisation of CM volumes, prioritisation of non-contrast imaging and/or alternative imaging depending on patient need without compromising diagnostic quality.

Conclusion: Critical lessons of sustainability essence are implicitly embedded in the policy guidelines issued during the periods of acute CM shortage in the COVID-19 pandemic. These lessons were themed around CM conservation based on: *type and priority of medical imaging investigation, kind of imaging modality* and *use of smaller vials over multi-dose vials packaging.*

Implications for practice: The temporary crisis-driven strategies may offer critical lessons for post-pandemic service delivery to enhance patient safety while saving cost and promoting greener practice via strategic clinical and operational monitoring of CM through policy renewal, education and training and collaboration with industry partners.

Introduction

Local and international travel restrictions[1] were implemented during the critical acute phases of the COVID-19 pandemic.[2] This unprecedented global change[3] was a necessary public health response to mitigate the spread of the virus and has impacted all sectors of the global economy including healthcare and its supply chain systems.[4] Consequently, access to essential healthcare supplies such as personal protective equipments (PPEs) and other clinical consumables were limited due to global supply chain disruptions.[4] The COVID-19 pandemic has therefore exposed vulnerabilities in the global healthcare supply chain and the challenges countries face in ensuring access to healthcare especially in a context where healthcare systems have been severely impacted.[5] The global shock in the supply chains stemmed from both disruptions in manufacturing coupled with the restrictions in the

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transportation sector, and the surges in demand for healthcare products exceeding supply capacity.[6]

In the period of this supply chain disruption, some medical imaging departments had to restructure their clinical workflows and examination protocols, in particular, due to the acute shortage of contrast media (CM) across some settings internationally.[4,7] CM remains a vital clinical consumable relied on within radiology for enhancement of diagnostic images[8] and across other medical specialities such as cardiology and urology for imaging-guided procedures.[9] According to Kabir and colleagues[10] the production of some commonly used iodinated contrast media (ICM), including iohexol (omnipaque) and iodixanol (visipaque), was halted during the critical acute phase of the pandemic as the major production plant was impacted by the lockdowns. A product shortfall of these essential CM agents was therefore anticipated shortly after this major production plant reported to be operating at 25% of their manufacturing capacity.[11] Despite China being the top supplier of numerous clinical goods, several healthcare organisations indicated that they had measures in place and that the Shanghai-China lockdown measures would not impact their operations.[12] Contrary to this, the shortage exposed inefficiency and poor resilience of the existing supply chain structures for these critical healthcare consumables.[10,13,14]

In response to the acute global shortage of CM, some local and international authorities in clinical imaging and allied fields issued guidelines to oversee the safe continuity of patient care despite the abrupt supply chain disruptions.[15] Particularly, these guidelines offered recommendations to alleviate the impact of the shortage of CM and to allow clinical staff to continue with patient diagnosis and care by providing images of diagnostic value.[16] The American College of Radiology (ACR) published the first guideline in May 2022 to address the shortage[16] followed by several other authoritative bodies and institutions with recommendations on how to mitigate the CM shortage impact through innovative and conservative strategies.

The environmental impact of clinical imaging including the use of ICM, has historically been underemphasised within the medical imaging community. Recent emerging evidence has recognised medical imaging operations to have significant ecological implications.[17] Specifically, the literature surrounding the environmental sustainability concerns associated with the use of ICM in radiology is growing.[8,18,19] This growing evidence base is crucial for guiding clinical imaging towards a more sustainable and greener practice.[66] With the current global drive for incorporation of green initiatives in all aspects of practice, it is critical for healthcare supply chains to prioritise sustainable models to alleviate environmental impact.[66] Thus, the CM supply chain disruptions due to the COVID-19 pandemic has offered an opportunity to revise and/or reconsider the approach to the usage of these products in diagnostic and interventional imaging studies.[8] The guidelines provided key recommendations relating to ICM volume optimisation and use of alternative imaging and modality substitution techniques that do not often require contrast agents and these may be relevant to protecting the environment.[16]

Together with lessons from sustainable healthcare[4,19] and the pandemic practices, this study aims to summarise the recommendations included in the guidelines with a focus on the implicit environmental sustainability considerations. With a consideration on applicability, this study aims to analyse how these temporary crisis-driven guidelines might inform the development of a more sustainable, long-term clinical guidelines and policies for CM usage in a manner that provides a balance for diagnostic quality, safety and cost-effectiveness. Of note, the scope of supply chain addressed in this study does not seek to prioritise contrast conservation over diagnostic quality but rather underscores the strategic allocation of limited resources by identifying which diagnostic procedures are most critical and should be prioritised for the use of ICM while adhering to environmental sustainability principles.

Methods

The content analysis approach[20] was employed to profile the environmental sustainability implications of the position statements and authoritative guidelines for contrast-enhanced imaging procedures following the acute CM shortage. This approach is deemed appropriate due to the qualitative nature of the data collected which focused on facts and information. Thus, the content analysis was employed in this context to investigate the implicit lessons with environmental sustainability bearings by systematically and objectively identifying characteristics of the messages for the purpose of making inferences.[20]

Inclusion and exclusion criteria

Formal documents including policy guidelines and position statements that have been published by institutions and authoritative bodies were included in the study. Grey literature and infomation[21] including organisational materials such as published reports, guidelines or evaluations that recommended the use of CM following its shortage at an institutional level were also included in the study. These documents fall within the framework of documents deemed suitable for consultation in health policy research according to Dalglish and colleagues.[22]

Notwithstanding, primary peer reviewed research, unpublished related research and literature reviews of any kind, opinion reports and published guidelines and recommendations that were not addressing the management of CM usage during the acute shortage caused by supply chain disruptions were excluded from the study.

Databases

Literature search was conducted across the following databases: PubMed, Science Direct, SCOPUS and Medline from April 2023 and May 2023. Additional search was conducted through Google Scholar and the reference list of relevant documents were hand searched for eligible articles/documents to ensure that no relevant documents were omitted.

Search strategy

Documents were identified through a federated (EBSCOhost) database search via the Bournemouth University online library. The search strategy was reviewed and refined by an expert librarian for appropriateness. The following search terms were used: COVID-19 pandemic, supply chain disruption, contrast media, shortage, protocols, practice guidelines. Boolean operators AND/NOT/OR were used together with the MESH/keywords for the document/literature search.

Selection strategy and data extraction

All the documents retrieved were pre-screened by title to identify relevant related documents and policy documents that meet the pre-defined inclusion criteria. Of note, studies that cited the use of contrast media following the supply chain disruption were also identified. The references were exported to the Mendeley reference management tool and duplicates were removed. The references were then screened for more documents and saved under the document portfolio. A quality appraisal was not performed as the included documents are not published journal articles (e.g., primary research), however, each document was assessed methodically for inclusion against the predefined criteria.

Data extraction was undertaken in two stages. First the key information from each document was obtained relating to the included author(s)/institutional names, country, and aim(s). A record of the extracted information was documented with the names of the sources in keeping with good practice.[23]

Data analysis and synthesis

Analysis of each of the documents was performed using the READ approach[22]. This provided a step-by-step guide to conducting the document analysis as described briefly:

Step 1. Ready your materials: This step involves setting parameters for the nature of documents to be analysed based on the research question and the time allocated. In this study, all the included documents were organised for further analyses.

Step 2. Extract data: Data extraction was conducted by reading each article entirely from the beginning to the end. This allowed the establishment of an overall understanding and extraction of specific data related to the research question. Data extracted was then used to build working theories that were useful analytical units and provided a basis for the discussion.

Step 3. Analyse data: The data collection and analysis are iterative and were characterised by an emergent design hence the findings informed how the obtained data was analysed and interpreted. Thus, the authors were already analysing data during the data extraction phase, forming theories, and modifying document selection criteria. The study sought a holistic view of the documents' answers to the themes developed during the extraction phase.

Step 4. Distil findings: Distilling findings involves the authors arriving at a saturation point in the study. It involves grouping the results and illustrating them in numerous ways to make them more presentable. The development of the themes was illustrated by illuminating different strands of the documents that developed the theme. The common comments were evaluated and developed into themes. The themes were developed by the integration of the key message contained in each of the documents analysed.

This approach provides a summary and systematic approach to the discussion of the relevant information under each of the developed themes. In-case analysis and cross-case analysis was developed to ensure the relationship in the data and the robustness of the synthesis was explored consecutively.

Results

17 articles/documents fulfilled the eligibility criteria and were included. Fig. 1 details the article screening process and the extracted data is tabulated (Table 1).

Of the included documents, 70% (n = 12) emanated from the United States of America and the rest from Australia/New Zealand and Canada. All the documents reviewed focussed on key aims that provide guidance on patient care prioritisation, ICM stock monitoring, contrast media conservation approaches, considerations for handling the contrast media shortage crisis and containment of its impact on patients' care and clinical practice at large (Table 1).

The format of presentation of the included documents were not uniform. They vary in length and complexity, and this is partly because they were authored by different health authorities and

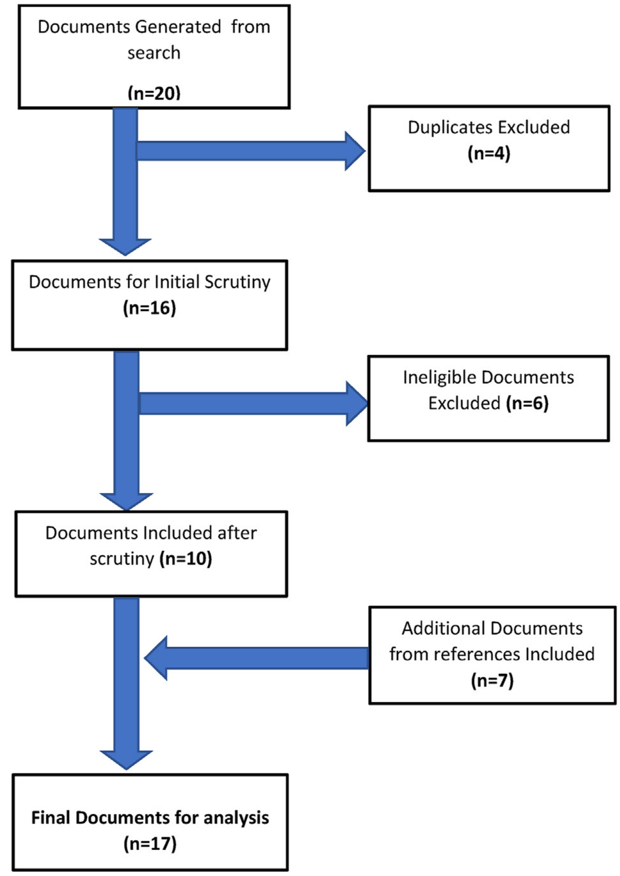

Figure 1. Flow Diagram showing the literature search process.

were jurisdictionally specific and for a varied healthcare target audience. Three broad themes were developed (Table 2) from the key findings, namely:

Theme 1: Conservation of contrast media based on the type of examination and priority.

Theme 2: Conservation of contrast media based on modality.

Theme 3: Sustainability by using smaller vials over multi-dose vials.

While individual guidelines addressed and contributed to multiple themes, of the included documents, 64.7% (n = 11)[36,37,39,40,44–46,49–52] addressed conservation guidelines and recommendations on the use of contrast media based on type of examination and priority. Approximately, 88% (n = 15) documents[36–46,48,50–52] focused on conservation of contrast media based on choice of applicable modality while almost 65% (n = 11) of these documents[36,38–40,42,43,46,47,49–51] highlighted conservation guidelines based on dose vials.

Discussion

The geographical density and distribution of the sources of the included documents may reflect practice variations and the degree of the regional impact of the acute ICM shortage. This also highlights the predominant ICM brands used regionally. For example, iohexol constitutes about 50% of the ICM market in the USA with over 120 million volumes of total contrast media usage recorded for CT scanning alone annually.[19] Consequently, the USA appears to be the most severely impacted by the shortage of iohexol which is the brand of contrast widely reported to have suffered shortage.

Table 1
Details of key findings and documents selected for the study.

No.	Document Reference &Journal	Country	Aim of Guidelines	Key Recommendations
1	American College of Radiology[36]	United States of America	To provide recommendations for how providers address emergency examinations locally.	Use alternative studies to answer the clinical question, use alternative contrast media agents, minimise individual doses and incorporate interdepartmental collaborations to ensure contrast supply is prioritised to limit usage.
2	Canadian Association of Radiologists[37]	Canada	To monitor shortage and efforts of manufacturers to mitigate the effects on Canadian patients.	Inventory supply should be monitored, studies prioritised accordingly, and protocols adapted to reduce ICM dose.
3	Radiological Society of North America[38]	North America	To ensure coordination between the radiologist and other specialists for optimal patient care through the global shortage of iodinated contrast media.	Use of alternative non-contrast studies like Ultrasound and MRI and repackaging higher volume single-use vials in smaller aliquots
4	The Royal Australian and New Zealand College of Radiologists[39]	Australia & New Zealand	To allow radiology practice and hospitals to implement various strategies to conserve supplies of contrast.	Individual doses reduction, use of alternative contrast media like barium-based products for oral opacification, utilisation of alternative modalities and interdepartmental collaborations.
5	American Society of Regional Anaesthesia and Pain[40]	United States of America	To address contrast media shortage and guide physicians on caring for patients including prioritisation of procedures.	Risk stratifies procedures that can be delayed, consider alternative modes of visualisation like ultrasound, gadolinium can be used in non-neuraxial injections and perform examinations that can be done without contrast with no contrast like sacroiliac and facet joint injections.
6	American College of Cardiology[41]	United States of America	To put resources to support clinicians, health systems, and hospitals to be able to manage the crisis.	Incorporate the use of non-contrast modalities to answer the clinical question. Conserve available supply and prioritise based on clinical risk and acuity.
7	American Society of Health System Pharmacists[42]	United States of America	To summarise the status of the current iodinated contrast media shortage and provide an outline of potential action for organisations to consider in managing the shortage	Contrast conservation should be done by developing policies or protocols to prioritise scans and patients based on clinical acuity. Repackaging of multi-dose and single-dose vials to ensure more contrast is conserved.
8	Spine Intervention Society & American Academy of Pain Medicine and are also endorsed by the American Academy of Physical Medicine and Rehabilitation (AAPMR), the American Society of Neuroradiology (ASNR), the American Society of Spine Radiology (ASSR), the North American Neuromodulation Society (NANS), the North American Spine Society (NASS), and the Society of Interventional Radiology (SIR)[43]	United States of America	To provide the best recommendations for the performance of interventional procedures in the setting of contrast media shortage	Each patient should be individually assessed depending on their situation. Vials may be repackaged for use with multiple patients.
9	Greater New York Hospital Association[44]	United States of America	To provide potential conservation strategies for iodinated contrast media	Hand on inventory be evaluated, seek alternative contrast media distributors, revaluate protocols. Facilities need to provide assorted options to cope with a limited iodinated contrast media supply and minimise the impact on clinical care.
10	American Urology Society[45]	United States of America	To provide strategies to mitigate impact of intravenous iodinated contrast media shortage	With guidance from the 2020 use of ultrasound for specific urology examinations like intermediate risk microhaematuria, delaying

Table 1 (*continued*)

No.	Document Reference &Journal	Country	Aim of Guidelines	Key Recommendations
				routine cancer surveillance or use of MRI with or without contrast.
11	Alaska Public Health[46]	United States of America	To alert the public and health facilities on the contrast shortage situation and propose strategies and recommendations, ensuring the continuity of clinical flow and patient management.	Use of alternative diagnostic modalities Alternative contrast brands Reduce individual doses. Prioritise supply based on patient acuity
12	GE Healthcare Pharmaceutical Diagnostics[47]	United States of America	To Prevent future global shortages of iodinated contrast media, highlighting the significant roles of the industry.	Healthcare industries must work together to develop industry-wide approaches to sustain growth, security, and to protect the future supply of these essential imaging agents. There is the need to facilitate innovations that aim to reduce the contrast dose delivered to each patient, reduce volumes of unused leftovers, and even recycle iodine from leftover contrast media for reuse. Facilities must adhere conservation strategies and protocols recommended by experts, organisations and regulatory bodies. Healthcare systems need to promote resiliency and increase hospital and wholesaler inventory, not just of contrast media but also the ancillary components needed for contrast administration.
13	The Canadian Agency for Drugs and Technologies in Health[48]	Canada	To summarise information on strategies to conserve ICM supplies during the shortage. It also identifies ways to strengthen the supply chain for ICM, and other critical health care products to better prepare for, and manage, potential future shortages.	Strategies aimed at substituting alternate imaging modalities and contrast agents as well as prioritising ICM procedures may be helpful to mitigate ICM shortages. Establishing an effective inventory management system and discouraging the reliance on a single ICM supplier and inventory management practice focused on the delivery of products when they are needed. There is the need to adopt centralized, province-wide supply chain systems that provide data on utilization and inventories across their jurisdictions.
14	Ontario Health[49]	Canada	To provide guidelines for ICM conservation and to guide clinical decision-making during the global ICM shortage.	Healthcare facilities must expand the use of non—contrast-enhanced CT scans, implement ICM dose reduction when possible while ensuring diagnostic image quality, tailoring ICM dosages to patient body weight, reducing wastage of ICM, and optimising technical parameters for image acquisition.
15	Minnesota Department of Health[50]	United State of America	To share information about current impacts and strategies being implemented by different systems, as well as any opportunities for resource sharing.	Short-term strategies to mitigate the iohexol shortage include establishing an incident command centre for monitoring the use of ICM, delaying elective contrast-enhanced CT examinations, CM dose reduction, and use of alternate imaging modalities if

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Table 1 (*continued*)

No.	Document Reference &Journal	Country	Aim of Guidelines	Key Recommendations
				applicable. Mid-term strategies include contrast media repackaging, multi-use and-multi-access strategies, communication and negotiation with payers on billing and reimbursement, and communication with ordering providers. Long-term strategies include advocating to facilitate expansion of contrast media manufacturing plants and institutional stockpiling of ICM supplies.
16	The Australian and New Zealand Society for Vascular Surgery[51]	Australia and New Zealand	To provide strategies for vascular surgeons to maintain high-quality patient care and decision-making during periods of restricted contrast availability.	Employ contrast media reduction techniques like direct reduction in CT examinations and alternative contrast agents. Multi-dose products to replace smaller volumes, use alternative brands of contrast media, use alternative modalities to contrast enhanced CT scans, increase follow-up screening interval and incorporate collective decision making. Contrast supplies both within and between healthcare institutions may need to be pooled and shared, with clear communication regarding the urgency and needs of each discipline in real-time across diagnostic and interventional radiology, interventional cardiology, vascular surgery and other specialties.
17	The Vizient Clinical Pharmacy Council[52]	United State of America	To serve as a resource if iohexol (Omnipaque) and/or iodixanol (Visipaque) experience supply disruptions due to shortages.	Reschedule non-emergent imaging or interventional studies which require iohexol, iodixanol, or other LOCM agents to conserve available inventory. Reserve iohexol and iodixanol for critically ill patients requiring CT studies or cardiac catherization lab interventions. If clinically appropriate, in coordination with radiologists, utilize other imaging study modalities such as magnetic resonance imaging (MRI), ultrasound, or nuclear studies. For oral administration, diatrizoate meglumine sodium (Gastrografin) or diatrizoate meglumine sodium (MD Gastroview) can be utilized as alternatives. For genitourinary administration, alternatives may include diatrizoate (Cystografin), iothalmate (Cysto-Conray II), or iothalmate (Conray 43).

CM is an essential consumable in the practice of clinical radiology,[24] with its vast applications ranging from enhancement and characterisation of normal and abnormal tissues and organs for diagnostic, evaluation or monitoring purposes. CM is used throughout specialised healthcare settings including, interventional and diagnostic areas in gastroenterology, cardiac, musculoskeletal, neurology, reproduction and vascular surgery as well as in the diagnostic imaging related to pain management, with radiology being the major user.[25]

Despite the critical role of CM in diagnostic imaging, concerns regarding its effects on the aquatic environment and indirect impact on climate change remains.[18] The production lifecycle,

Table 2
Thematic summary of key findings obtained from the included documents.

Document and Reference Journal	Theme 1 Conservation of contrast media based on type of examination and priority.	Theme 2 Conservation of contrast media based on modality.	Theme 3 Sustainability by using smaller vials over multi dose vials.
American College of Radiology	Higher concentration agents be reserved for angiograms and multiphase studies.	Use alternative modalities that do not require the use of contrast media for example nuclear medicine.	Repackage high volume single use vials.
Canadian Association of Radiologists	Delay non urgent contrast enhanced examinations.	Evaluate requisitions to determine if alternative modalities can be used without sacrificing image quality.	
Radiological Society of North America		Alternative non contrast studies in ultrasound and MRI should be considered.	Multi use to single use vials.
The Royal Australian and New Zealand college of Radiologists	High concentration for multiphase and angiographic studies.	Utilise alternative modalities that do not require ICM.	Repacking into smaller aliquots to reduce waste.
American Society of Regional Anaesthesia and Pain	Lumbar interlaminar, cervical facet interventions may be performed without ICM.	Ultrasound guided modality may be considered for some examinations.	Dose splitting/repackaging advised over multidose vial use for patients.
American College of Cardiology		Identify alternative non contrast studies to answer a clinical question.	
American Society of Health System Pharmacists		Procedure performed using alternative techniques that do not need ICM.	Repackaging of multi dose vials to single dose vials.
Spine Intervention society		Evaluate orders to determine if alternative modality can be used.	Pharmacists repackage vials for multiple patients.
Greater New York Hospital Association	Delay routine cancer surveillance.	Use MRI with and without contrast for tumour staging.	
American Urology Society	Defer low risk imaging like annual staging.	Use alternative modalities.	
Alaska Public Health	Prioritise supply based on patient acuity	Use of alternative diagnostic modalities	Alternative contrast brands Reduce individual doses
GE Healthcare Pharmaceutical Diagnostics			There is the need to facilitate innovations that aim to reduce the contrast dose delivered to each patient, reduce volumes of unused leftovers, and even recycle iodine from leftover contrast media for reuse.
The Canadian Agency for Drugs and Technologies in Health		Strategies should be aimed at substituting alternate imaging modalities.	
Ontario Health	Healthcare facilities must expand the use of non–contrast-enhanced CT scans for appropriate examinations.		implement ICM dose reduction when possible while ensuring diagnostic image quality, tailoring ICM dosages to patient body weight, reducing wastage of ICM, and optimising technical parameters for image acquisition.
Minnesota Department of Health	Delaying elective contrast-enhanced CT examinations.	use of alternate imaging modalities if applicable.	CM dose reduction contrast media repackaging, multi-use and-multi-access strategies,
The Australian and New Zealand Society for Vascular Surgery	Directly reduce contrast-enhanced CT examinations and increase follow-up screening interval and incorporate collective decision making. Contrast supplies both within and between healthcare institutions may need to be pooled and shared, with clear communication regarding the urgency and needs of each discipline in real-time across diagnostic and interventional radiology, interventional cardiology, vascular surgery, and other specialties.	use alternative modalities	Multi-dose products to replace smaller volumes, use alternative brands of contrast media.
The Vizient Clinical Pharmacy Council	Reschedule non-emergent imaging or interventional studies which require iohexol (Omnipaque), iodixanol (Visipaque), or other LOCM agents to conserve available inventory. Reserve iohexol (Omnipaque) and iodixanol	If clinically appropriate, in coordination with radiologists, utilize other imaging study modalities such as magnetic resonance imaging (MRI), ultrasound, or nuclear studies	

(*continued on next page*)

Table 2 (*continued*)

Document and Reference Journal	Theme 1 Conservation of contrast media based on type of examination and priority.	Theme 2 Conservation of contrast media based on modality.	Theme 3 Sustainability by using smaller vials over multi dose vials.
	(Visipaque) for critically ill patients requiring CT studies or cardiac catherization lab interventions. For oral administration, diatrizoate meglumine sodium (Gastrografin) or diatrizoate meglumine sodium (MD Gastroview) can be utilized as alternatives. For genitourinary administration, alternatives may include diatrizoate (Cystografin), iothalmate (Cysto-Conray II), or iothalmate (Conray 43).		
Thematic Summary	Out of the 17 documents analysed, 11 provided specific recommendations for clinicians to prioritize examinations based on the type of exam being conducted, thereby promoting the conservative use of contrast media. This theme does not prioritize contrast conservation over diagnostic quality but rather underscores the strategic allocation of limited resources by identifying which diagnostic procedures are most critical and should be prioritized for the use of ICM. The recommendations often categorize exams based on urgency, patient condition, and potential impact on treatment decisions. This approach not only ensures that patients in most need receive essential imaging but also aligns with the broader goal of reducing overall contrast media consumption during periods of scarcity. By prioritizing exams, healthcare facilities can mitigate the impact of supply chain disruptions on patient care while also contributing to more sustainable imaging practices by minimizing waste and optimizing the use of available resources.	The analysis revealed that 15 out of the 17 documents emphasised the importance of considering alternative imaging modalities that do not require the use of ICM but still offer significant diagnostic value based on the clinical question at hand. This theme highlights a shift towards modality substitution as a strategy for conserving contrast media. For instance, in cases where ultrasound or MRI could provide sufficient diagnostic information, these modalities are recommended over CT scans that require ICM. Our analysis thread some aspects of these recommendations with caution by considering usage time, safety, energy consumption and carbon footprint implications, especially with MRI and CT substitution. This not only helps in conserving the scarce resource but also potentially reduces patient exposure to ionizing radiation and contrast-related adverse events. Furthermore, the exploration of alternative modalities is in line with environmental sustainability goals by potentially reducing the carbon footprint associated with the production and disposal of ICM, as well as encouraging the adoption of imaging practices that have a lower environmental impact.	Among the documents analyzed, 11 recommended the repackaging of vials and the reduction of contrast media doses as effective strategies for conservation. This theme focuses on the operational adjustments that can be made to extend the availability of contrast media during shortages. By using smaller vials or repackaging larger, multi-dose vials into smaller doses, healthcare providers can significantly reduce waste and ensure that contrast media is used more efficiently. This practice not only aids in stretching limited supplies during acute shortages but also aligns with broader environmental sustainability goals by minimizing waste. The theme reflects a practical approach to resource conservation, emphasizing the need for healthcare systems to adapt their practices not only in response to immediate challenges but also as part of a long-term strategy for more sustainable and responsible use of ICM.

distribution, and disposal of ICM involve the use of chemicals and energy-intensive processes that contribute to greenhouse gas emissions. These processes generate waste that can indirectly contributes to the overall carbon footprint of the healthcare sector, which consequently impacts climate change. Within the wider context of the environmental impact of radiology, CM remains one of the major public health concerns[26] due to current emerging evidence[8] revealing significant traces of ICM in water bodies. For example, research have shown that about 80% of pharmacological effluence within hospital wastewater system[27] is related to ICM and this could be attributed to its wider use across healthcare subdisciplines.

Although, modern ICM is considered to have a high safety profile with a reported excretion rate of 50% through the urinary tract within 2 h after administration,[28] the excreted waste ends up in water bodies.[18,29] This was evidenced by research that found traces of ICM and was attributed to its short water cycles.[29] Consequently, more water bodies have been found to have iohexol which is the ICM component that tests positive in water bodies.[30]

Hospital wastewater is not treated separately, instead it is released into the local sewage systems together with domestic sewage waste[31] and treatment requires several steps of which hospital wastewater treatment plants[32] cannot handle, thus, the contrast residue remains in surface and drinking water.[30] Additional concerns relate to the concomitant effect on drinking water sources, the additional water purification efforts and the formation of toxins by the breakdown of the constitute compounds.[11,33] Of critical concern is the ability of active constituents of CM agents to react with common disinfectants such as chlorine in the presence of organic matter to produce iodinated disinfection byproducts (IDBPS) with much higher toxicity than the conventionally known disinfection by-products (DBPS).[11] Consequently, the treatment, purification and mineralisation processes of these water systems are relatively more challenging.[11]

Recommendations for reducing the environmental impact of ICM include recycling leftover contrast media,[47] collection of urine in urine bags post-contrast investigations,[34] optimising the volume of CM (i.e. injecting less volume) and/or employing alternative imaging techniques that do not require CM.[23,34,35] Reinforcement of some of these recommendations became inevitable following the shortage of CM due to the unexpected supply chain disruptions in the COVID-19 pandemic. This has provided an opportunity to re-evaluate clinical practices to embrace the growing concern on environmental sustainability as discussed in the themed suggestions.

Theme 1: conservation of contrast media based on type of examination and priority

Mitigation of the impact of CM shortage through prioritisation and the type of examination was widely recommended across the included documents and position statements. The key suggestions via this approach are the use of alternative contrast agents or imaging techniques such as MRI (specialised or superior contrast enhanced sequences with minimal energy requirements) and ultrasound which do not require iodinated contrast media and prioritising the examinations that could not be conducted with contrast enhancement using CT. The use of alternative imaging techniques and CM brands, careful protocoling and prioritising examinations in accordance with urgency have been widely reported and strongly recommended across almost all the included documents.[36–52] These contrast conservation approaches potentially reduce the amount of ICM used daily and consequently lessen the amount of CM that could have potentially gone into the aquatic environment through excretion. Although, this has not been quantified in any study at this time, however, based on the reported daily consumption, it is possible to project how much contrast would have been saved following these conservation approaches.

CM conservation by examination type was also recommended by 11 out of the 17 included documents. By this method, non-contrast CT examination has been strongly advocated.[36,38,40,41,45,46,48–52] As this may not be ideal for most CT examinations, it highlights the importance of considering all available opportunities with minimal environmental consequence. Much as this may pose some degree of inconvenience to clinicians, it offers innovation in clinical decision making and could positively impact the environment. Nevertheless, it must be considered that environmental considerations should not override the clinical necessity and diagnostic integrity of imaging procedures, especially for CM indispensable procedures. This warrants the need to explore more innovative strategies and artificial intelligence models that could serve these purposes in radiology by balancing the need for diagnostic precision with environmental stewardship, wherever feasible. The ACR[36] for example, was the first to release guidance recommending that "contrast media of high concentration should be reserved for angiograms and multiphase examinations". Similar guidance[53] implemented at the Yale School of Medicine recommended specific doses of contrast media for specific examinations as follows: a multiphase abdomen CT -75ml instead of the original 80 ml,[53] 100 ml instead of 150 ml for liver their donor protocol. This represents a significant CM savings; for instance, if the recommended volume of contrast for liver donor protocol are followed, about 5000 ml of CM would have been conserved for every 100 examinations which would also translate to significant greener practice. Thus, these recommendations are of sustainability essence to the practice of clinical radiology and should be encouraged in practice moving forward.

Theme 2: conservation of contrast media based on modality

Conservation of CM based on modality was an aspect consistently reported across all documents.[36–52] Although some documents were silent on the specific alternative modalities, five[38,40,44,45,52] of the 17 documents specifically recommended MRI and ultrasound which scantily use contrast as compared to CT. It was, however, emphasised that considerations should be given to the ability to achieve the desired diagnostic outcome without compromising on the quality of clinical care the patients receive. For example, blood vessels and soft tissues could be examined with dedicated MRI or ultrasound protocols without using contrast as opposed to CT where CM administration is an integral element of most of its protocols.[35] The decision for contrast-enhanced CT should be carried out considering the superiority of its diagnostic efficacy as against other modalities. Notwithstanding, it is also critical to consider the clinical risks and the potential environmental impacts and administer the lowest possible dose.[54]

Applicable measures that contribute to the conservation of CM based on modality, which include the vetting for CT scan requests[71] and procedures which are achievable via other modalities with less resource, should be encouraged. Where appropriate, suggestions for adjusting CT protocols to allow radiographers to scan specific patients with as minimal as reasonably acceptable CM or even without contrast when feasible, should be encouraged.

The use of alternative diagnostic modalities to achieve results is of sustainability essence since diverting contrast-enhanced examinations to modalities that do not require ICM eventually reduces the frequency of CM consumption. Of note, the intensity of energy consumption of the alternative imaging modalities should be a critical consideration[19,72] without necessarily sacrificing diagnostic quality and patient care outcomes. To enhance the process of modality substitution, carbon footprints associated with imaging equipments should be developed to guide clinicians in their clinical requisition for making environmentally friendly choices for quality patient care.[69]

Additionally, reducing the number of examinations done through CT significantly reduces the amount of CM that could potentially end up in surface and drinking waters.[56] This directly impacts the environment since CT requires the largest quantities.[55] This is a behavioural change in clinical radiology practice, hence, embracing the recommendation as a long-term policy will allow clinicians to actively contribute to the efforts in mitigating climate change by paying critical attention to the environmental impacts when using these services.

Theme 3: sustainability by using smaller vials over multi-dose vials/bottles

Within most hospital settings, pharmaceutical waste products originating from wards could be generated via partially used or unused dosage forms, patient's personal medications and expired drugs.[57] Dlotko and colleagues[58] compared the cost and wastage of CT contrast associated with single and multidose CM bottles and demonstrated that switching from a single dose to multidose bottles led to the conservation of 86% of contrast from going waste. The authors added that switching from a syringe to a syringeless power injector also reduces CM waste. The use of multidose vials/bottles and power injectors allows administration of the precise volume of CM required and allows the preservation of any leftovers.

Consistent with the findings of Dlotko and colleagues, multidose vials have been recommended over single-dose vials for cost minimisation while maintaining the quality of contrast-enhancement across diagnostic images.[59,60] These recommendations were grounded on reduced environmental impact and economic considerations to effectively make use for conserved CM that could sustain imaging facilities in cases of possible supply chain disruptions. However, recent research by Pepin et al.[70] has demonstrated that a diversified inventory of vial sizes can be an effective alternative strategy for optimising ICM use and minimising waste. This approach may offer a tailored solution that aligns with the goals of precision medicine and sustainability. Consequently, healthcare facilities should consider a comprehensive analysis of their ICM usage patterns, patient demographics, and procedural requirements to determine the most appropriate and sustainable inventory management strategy, whether it be through the use of multi-dose vials, a variety of single-dose vial sizes, or a combination of both. The over merits adopted strategy should be of a greener and more sustainable practice in radiology.

The use of power injectors prevents contrast and syringe wastage. This is because with the use of syringes, there is a need to constantly discard and use new syringes for each patient and the potential to use multiple syringes for one patient is very high. This obviously has negative sustainability implications both from the resource utilisation and economic standpoint. Of note, while the included documents did not emphasise the environmental sustainability implications of CM conservation via these routes, it is worthy to note that significant eco-friendly gains could be made through the implementation of this approach.

Among the measures to contain the CM shortage following the supply chain disruption, 8 of the studies recommended repackaging of CM into multidose vials in accordance with the findings of Dlotko and colleagues.[58] One study, however, recommended repackaging CM into small vials; this approach is not sustainable as it involves using extra plastic bottles and syringes. Furthermore, use of multi-dose bottles and syringeless injection systems aid in eliminating the residual contrast media in remaining bottles after use by over 70%, reduce the use of plastic polymer, while reducing the cost of medical and pharmaceuticals supply.[61]

Strategies and recommendations for a sustainable contrast media supply chain

Strategies

The implications of the failure of various healthcare supply systems were dire as in the case of CM. This necessitates the need to introduce several critical risk and resilience strategies into the healthcare supply chains to address the well-being of patients. In an attempt to build resilience into the healthcare supply chains,[62,67] four strategies are proposed including *preparation, robustness, recovery, and adaptability*.[63–65]

Preparation involves healthcare supply chain being able to anticipate disruptions hence the need to monitor the environmental triggers, the potential impact and mitigation strategies.[65] This enables hospitals to focus on augmenting their internal capabilities, trust, local facilities, and strategies which could enable them to withstand potential disruptions and equip supply chains to recover from disruption.[65,68]

Robustness allows coping with a disruption by maintaining a desirable level of performance. This can be implemented through practices like postponing, having a flexible supply base and transportation.[65,68] It allows the healthcare supply chains to activate other resources prepared by the anticipation to limit the impact of the disruptions.

Recovery allows the supply chains to return to normal since it can integrate the needed resources to overcome the disruption. The adaptability of a supply chain needs robustness and recovery to grow because it analyses the causes of the disruption and develops capabilities to better prepare for a new occurrence.

Recommendations

Policy formulation. Environmental sustainability must be factored into the development of policies and protocols, both locally and internationally. In line with the recommendations professed in the documents, local policies and protocols for example must be able to advise alternative imaging during vetting of radiology requests that would require minimal or no CM to achieve radiological images that are diagnostically optimal. There must be a conscious effort and commitment towards enforcing these policies by all stakeholders. Industry players who are involved in manufacturing CM must liaise with clinicians to devise ways of conserving CM and to ensure protection of the environment.

Awareness creation. Sustainability related to contrast media management and potential environment concerns should be considered in the teaching of pharmacology within the context of radiology. This should highlight key environmental sustainability concerns and how the practice affects the climate and consequently human lives and other living organisms in general. The learning outcomes of educational and continuous professional development programmes should be expanded to include the key sustainability issues in radiology/radiography and radiotherapy, and this should include CM. This will create awareness within both the clinical and academic environments.

Moreover, there is a need to focus on research that involves innovative approaches through which healthcare practices could be made more sustainable. Patient education could also play a significant role through a wider stakeholder consultation and collaboration in the efforts to mitigate the environmental challenges within radiological practice.

Study limitations

The study relied solely on official documents and position statements that are available and accessible in English and in the public domain. This excluded documents that may have been important to the study but not accessible and in other languages. Moreover, no documents were found on continents like Africa, Europe, and Asia hence a global conclusion cannot be made. While our review draws primarily on institutional, regulatory, and authority documents from governing bodies of radiology, we recognise that these sources of evidence, including position statements and expert opinions may limit the external validity of our findings to some extent. However, it is important to note that the nature of the topics covered in our review often requires the integration of practical, regulatory, and safety considerations. Future research could aim to complement these authoritative sources with higher levels of evidence where available, to further validate and refine the recommendations and insights provided by these governing bodies.

Future directions and conclusions

The impact of ICM on environmental sustainability has had increased concerns within the past few years. Hitherto, ICM use has been on the ascendency and in large quantities during computed tomography examinations. There is growing body of research on the impact of healthcare supply chains on the environment. Sustainable and environmentally friendly strategies of healthcare providers and their supply chains are therefore gaining public interest.

CM shortage due to the supply chain disruption during the pandemic era has led to the development of policies and recommendations to contain and minimise the impact of the shortage.

Key recommendations include encouraging multidose vials use, or a diversified inventory of vial sizes, use of alternative imaging modalities or imaging protocols that do not require CM and/or use of less volumes of CM where possible are critical to ensuring a greener clinical practice. The primary focus of these policies and recommendations are to conserve CM and to reduce effects that the shortage would have on patient care. Despite the benefits of these policies and recommendations, they failed to clearly highlight the environmental sustainability implications they contain. Highlighting the environmental sustainability opportunities embedded in these recommendations could have achieved a dual benefit, containment of both clinical care impact and long-term benefits in relation to environmental sustainability and planetary health.

In conclusion, the policy guidelines issued in response to the acute CM shortage during the COVID-19 pandemic inherently incorporate key principles of sustainability. These lessons relate to minimising contrast media usage through strategic clinical approaches without compromising diagnostic quality. These lessons need to be embedded in post-pandemic practice for patient safety while saving cost and the environment through education and training, collaboration with industry partners and policy renewal. Where necessary, these recommendations should be modified to suite local practice to maintain high quality and optimal radiological care while protecting the environment.

Conflict of interest statement

All authors have no conflicts of interests to declare. Of note, TNA is a member of the editorial board but was blinded to the decision-making process.

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